Cassini Mission at Saturn

Cassini Power Subsystem

Jonathan Grandidier, John B. Gilbert and Gregory A. Carr

Jonathan Grandidier PhD, Technologist, February 28th 2017
Nuclear and Emerging Technologies for Space 2017, Orlando, Florida

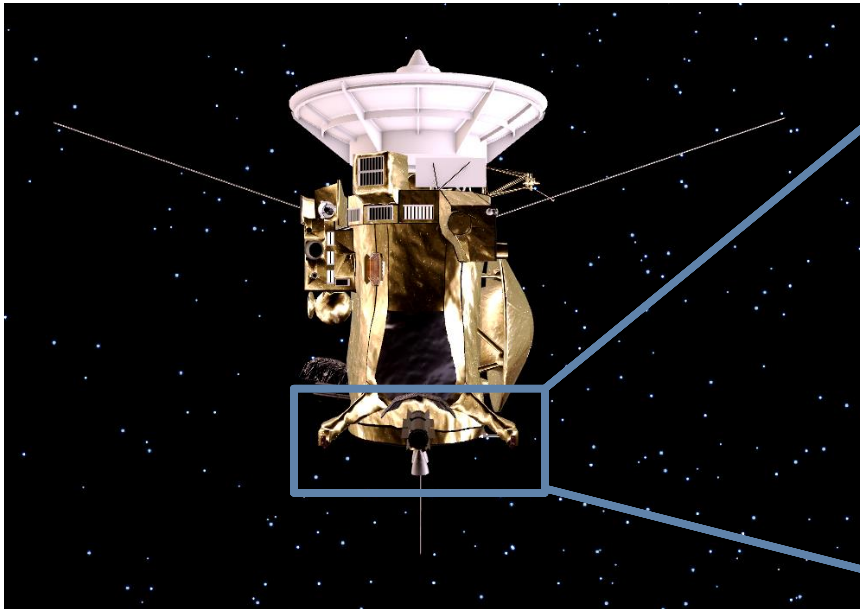
Jet Propulsion Laboratory
California Institute of Technology

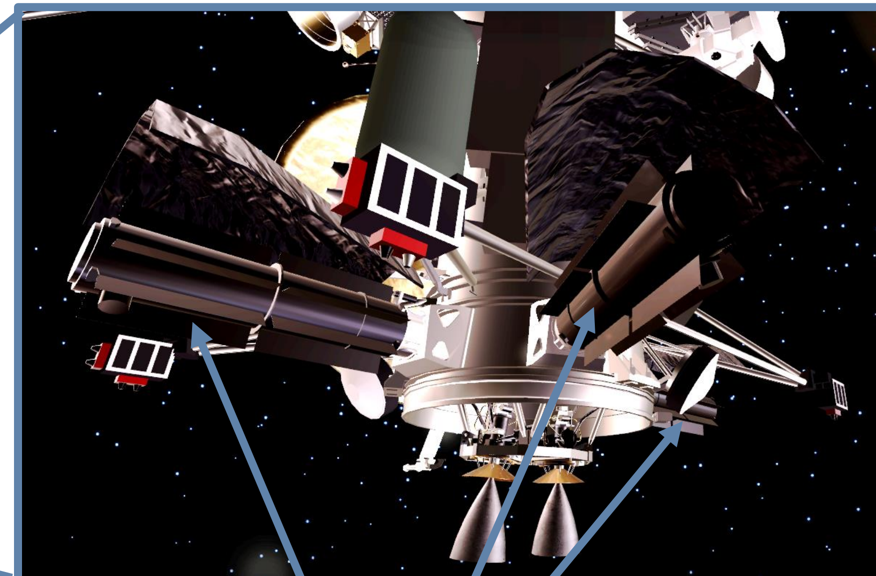
Summary

- Cassini spacecraft and Radioisotope Thermoelectric Generators (RTGs)
- Mission Overview
- Cassini Power Subsystem
- Cassini Power at launch
- Cassini Power over time
- Conclusion

Cassini spacecraft and Radioisotope Thermoelectric Generators (RTGs)

Credit NASA





<u>Dimensions</u>: 6.7 meters high; 4 meters wide
<u>Launch Weight</u>: 5,712 kg with propellants
<u>Orbiter science instruments</u>: 12 instruments
<u>Power</u>: 882.1 watts at beginning of mission and ~600 watts at end of mission 09/15/2017 from radioisotope thermoelectric generators (RTGs)

Three General Purpose Heat Source Radioisotope Thermoelectric Generators (GPHS -RTGs) on the Cassini spacecraft

Cassini spacecraft and Radioisotope Thermoelectric Generators (RTGs)

October 9, 1997: At Launch Complex 40 on Cape Canaveral Air Station, workers are installing three Radioisotope Thermoelectric Generators (RTGs) on the Cassini spacecraft. Cassini is undergoing final preparations for liftoff on a Titan IVB/Centaur launch vehicle, with the launch window opening at 4:55 a.m. EDT, Oct. 13

Credit
NASA

Cassini spacecraft and Radioisotope Thermoelectric Generators (RTGs)

32.7 kg of plutonium dioxide

82% ^{238}Pu

Produces heat by α–decay into ^{234}U.

Total heat output of all three RTGs: 13.2 kW thermal at BOL. Electrical output is 882.1 W, ➔efficiency is 6.69%.

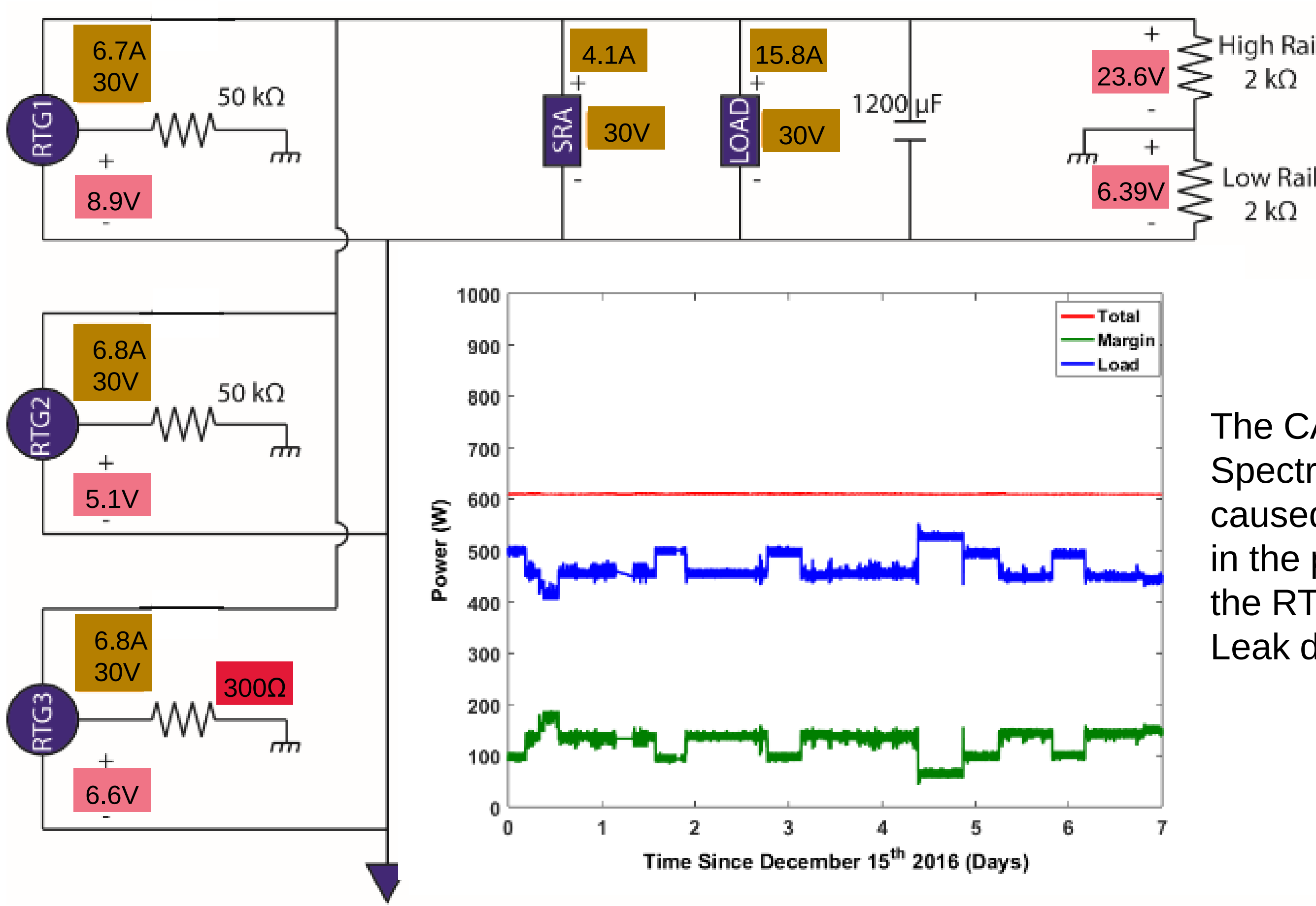
RTGs fuel composition at beginning of life

	RTG 1	RTG 2	RTG 3	Total
^{238}Pu Weight (g)	7693.70	7774.06	7756.40	23224.15
^{239}Pu Weight (g)	1426.55	1447.79	1441.78	4316.11
^{240}Pu Weight (g)	199.87	212.38	202.62	614.88
^{241}Pu Weight (g)	20.24	20.75	20.54	61.53
^{242}Pu Weight (g)	11.84	14.13	12.53	38.50
^{236}Pu Weight (g)	1.07E-04	1.14E-04	1.13E-04	3.34E-04
Total Pu Weight (g)	9352.19	9469.12	9433.87	28255.17
Other Actinides (g)	235.07	166.96	184.74	586.77
Impurities (g)	14.46	15.54	14.26	44.26
Oxygen (g)	1275.94	1243.13	1263.33	3782.40
Total Fuel (g)	10877.65	10894.75	10896.20	32668.60
Pu-238/Total Pu (%)	82.27	82.10	82.22	82.19
Avg. Pellet Weight (g)	151.08	151.32	151.34	151.25
Heat Output (Wt)	4368.06	4413.78	4403.68	13185.52
Avg. Pellet Heat (Wt)	60.67	61.30	61.16	61.04
Avg. Pellet Density (g/cc)	9.83	9.94	9.90	9.89
Activity (Curies)	133934	135368	135040	404342

Astronautics, L.M., *Cassini RTG Program*. 1998.

Cassini Power Subsystem

LOAD: series of 192 Solid State Power Switches (SSPS) – not shown



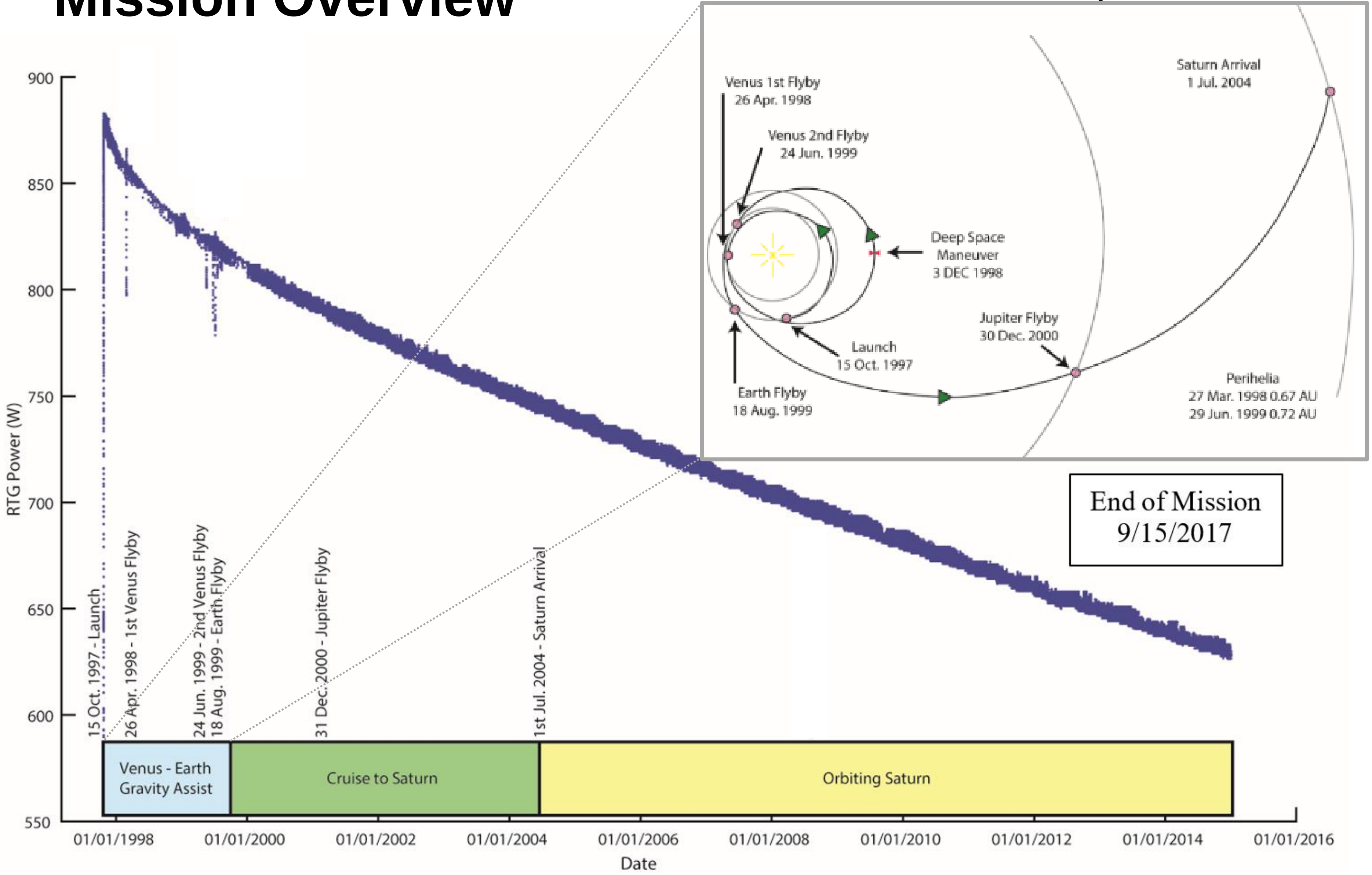
The CAssini Plasma Spectrometer (CAPS) caused a series of shorts in the power bus and in the RTG3 case

Leak due to tin whiskers

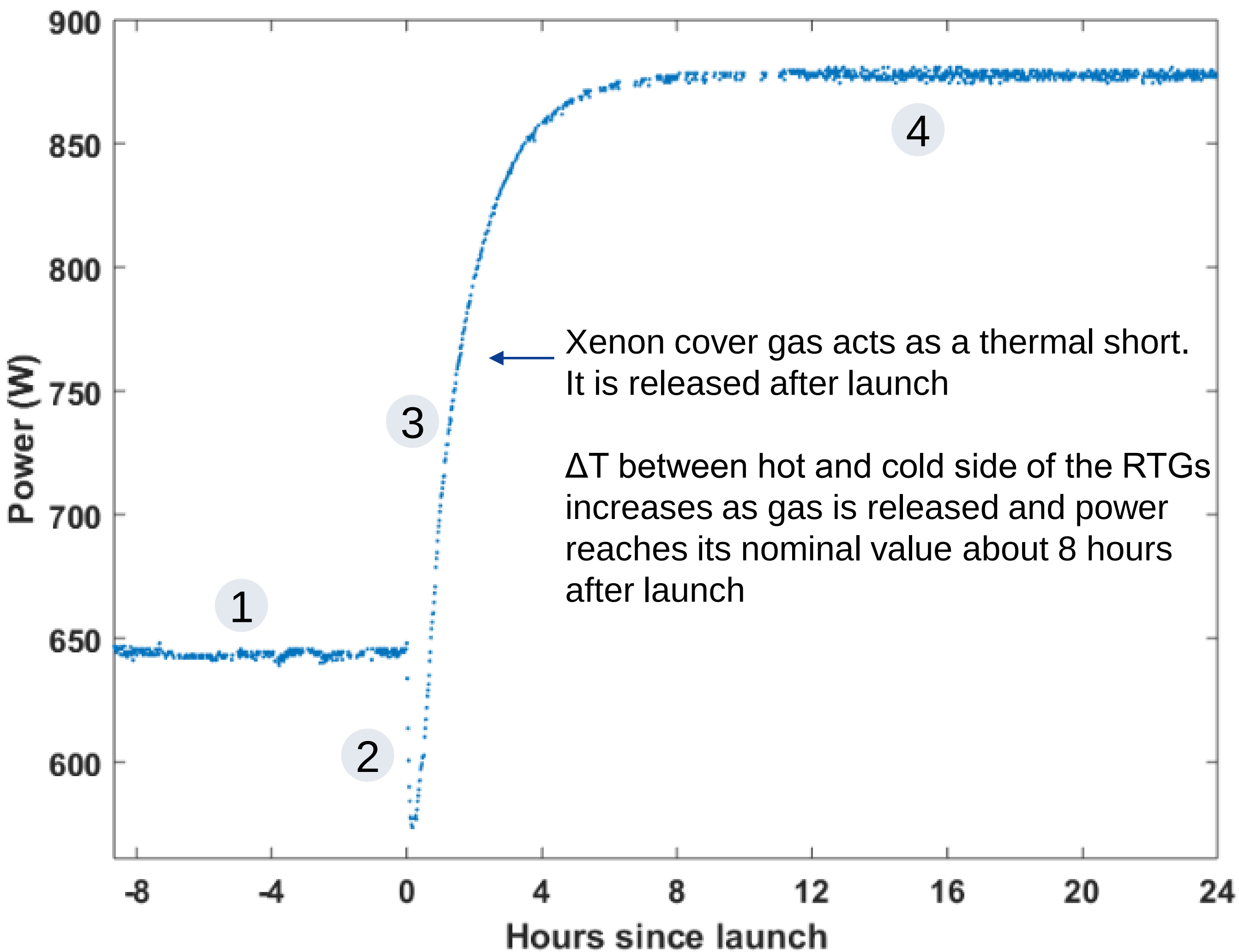
Cassini functional block diagram including RTGs, Shunt Regulator Assembly (SRA) and Load, balanced bus divided into two rails: High Rail and Low Rail (developed by JPL and demonstrated high reliability)

Mission Overview

Cassini's seven-year Venus-Earth gravity assists and cruise to Saturn between launch on 15 October 1997 and Saturn arrival on 1 July 2004.



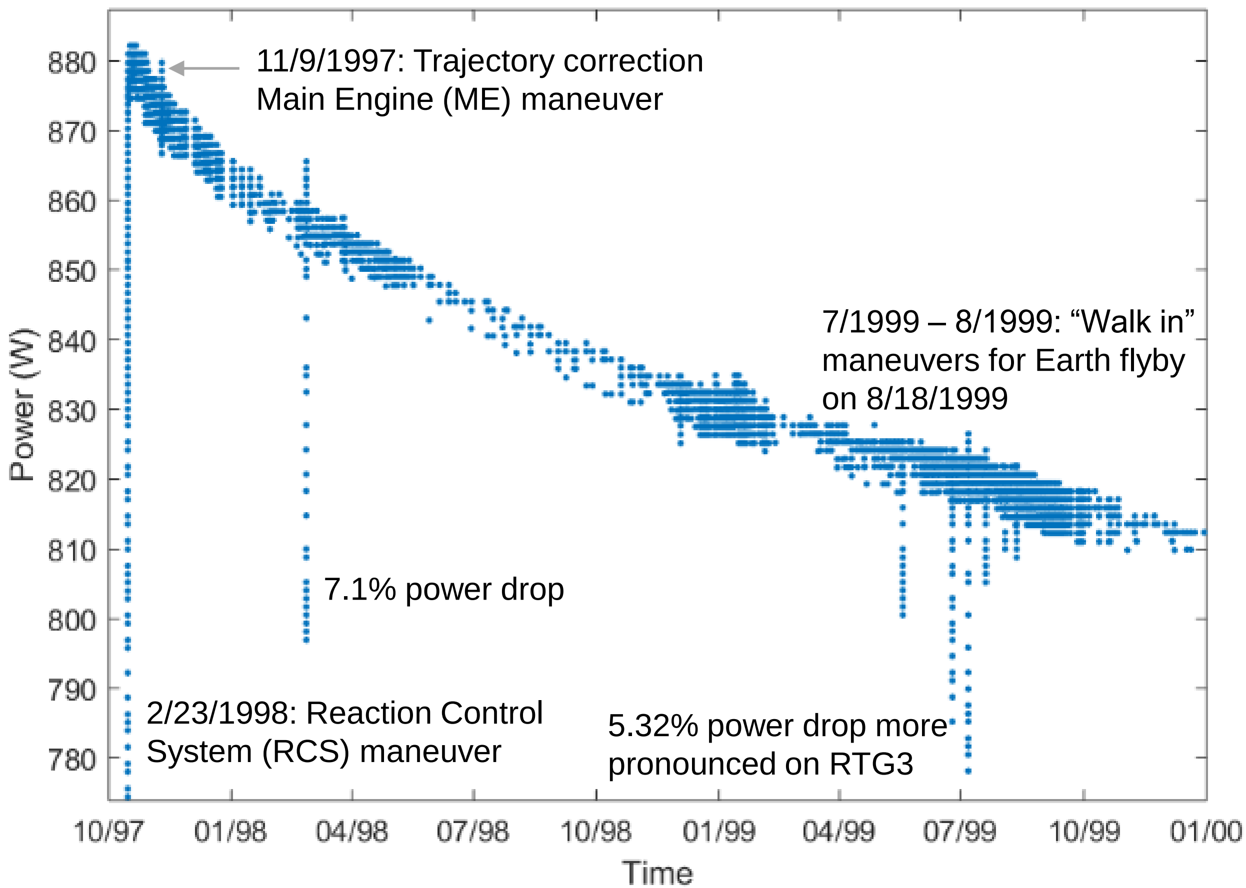
Cassini Power at launch



8:43 a.m. UTC, Oct. 15 1997

1. Steady state prior to launch
2. After launch: As convection loss decreases, cold side temperature increases
3. Xenon cover gas is being released
4. Power reaches its nominal value 882W

Cassini Power over time

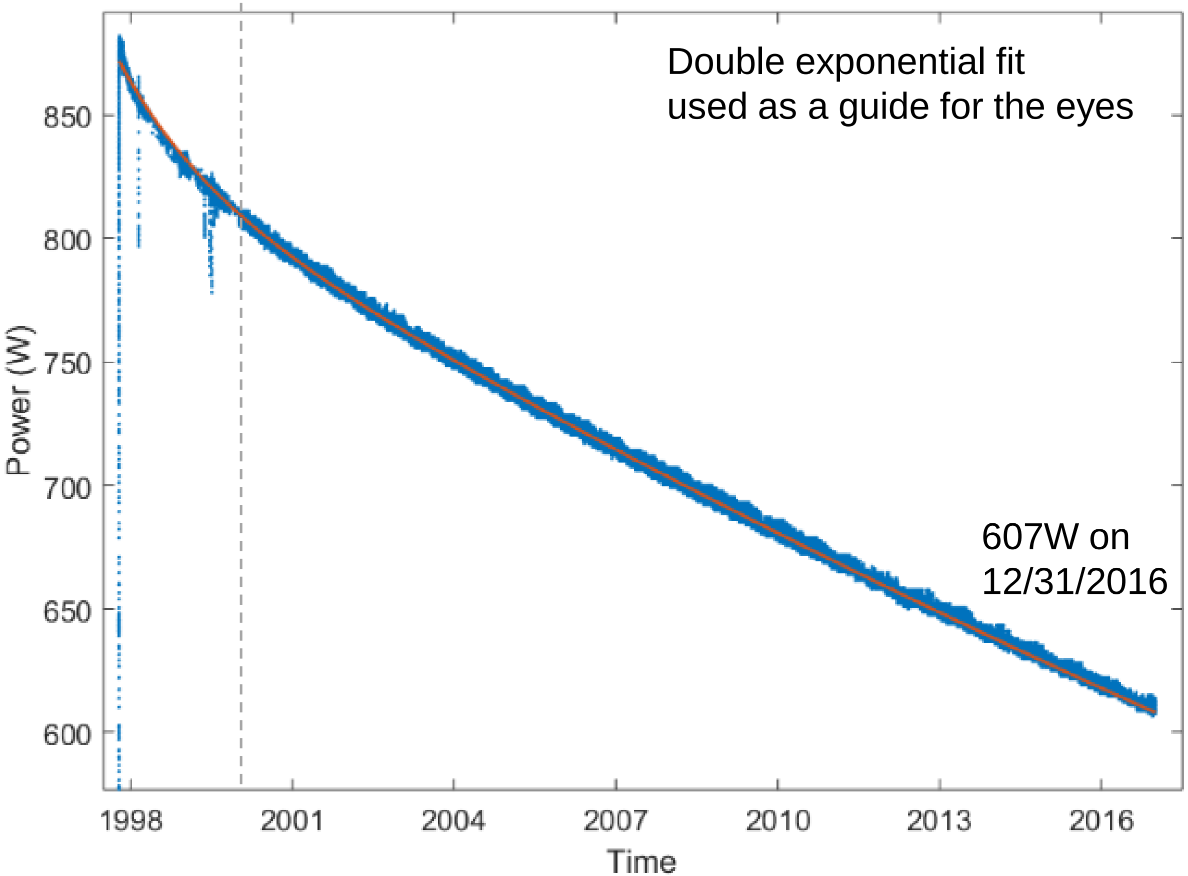


Maneuvers executed during Venus-Earth gravity assists had an attitude control variation that exposed the cold side of the RTGs to the sun. This reduced ΔT between hot and cold side of the RTGs and therefore the overall power output.

Cassini Power over time

Accelerated decay due to dopant precipitation in SiGe thermocouple

Trend follows ^{238}Pu decay rate of 87.7 years half life



Expected power at the end of mission 600W on 09/15/2017 Calculated using the “lifetime prediction and performance model”

Complete Cassini telemetry data between launch and 12/31/2016

Conclusion

The history of Cassini power subsystem and RTGs from spacecraft integration to current power production were presented

Cassini has been using RTGs successfully for almost 20 years

Cassini's balanced bus divided into two rails demonstrated high reliability and electrical shorting tolerance

Environmental effects due to spacecraft attitude control had significant impact on power output and later RTG designs

Cassini's power decay showed 2 very distinct periods

1) Accelerated decay due to dopant precipitation
2) Exponential decay due to ^{238}Pu decay rate of 87.7 years half life

Acknowledgements

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

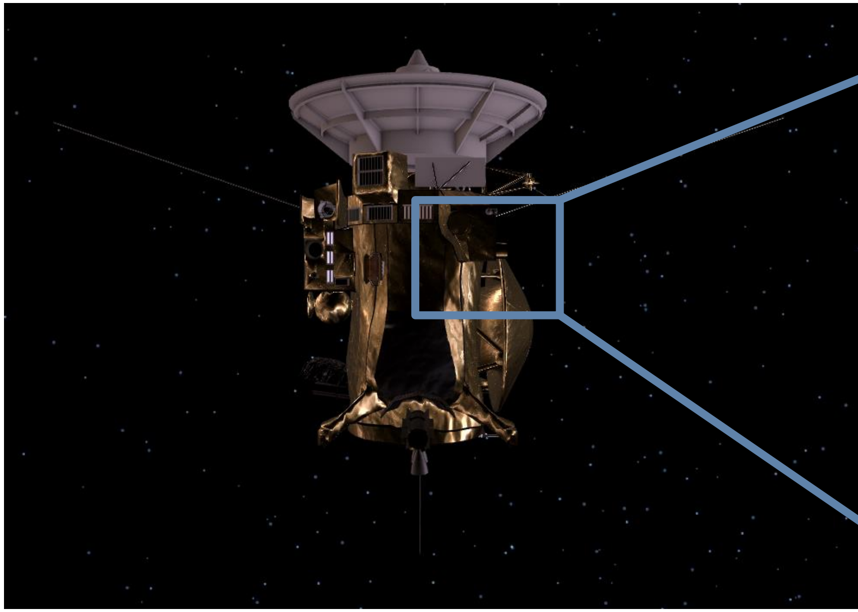
The authors would like to acknowledge the valuable contributions from Terry J. Hendricks, Bill J. Nesmith, Laura Burke and Julie L. Webster.

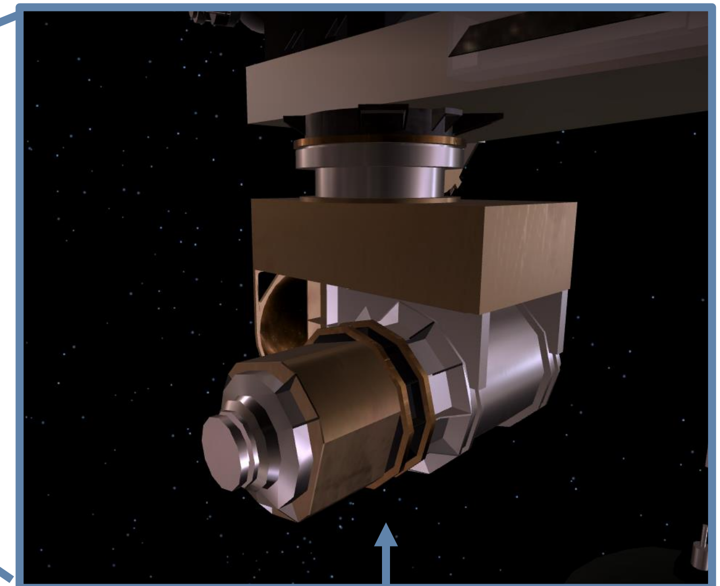
Picture of Earth from Cassini at Saturn

BACKUP SLIDES

Cassini Plasma Spectrometer (CAPS)

Credit NASA





Cassini’s Plasma Spectrometer, called CAPS, is an in situ instrument, detecting and analyzing plasma (ions and electrons) in the vicinity of the spacecraft. Scientists have used the instrument’s data to learn about the composition, density, flow, velocity and temperature of ions and electrons in Saturn's magnetosphere.

The Cassini Plasma Spectrometer measures energy and electrical charges

Cassini Plasma Spectrometer (CAPS)

During Saturn tour operations, CAPS experienced a series of short anomalies that affected the power subsystem

28 June 2006: CAPS experienced a series of short accompanied by Low Rail to chassis short that self-cleared within 48 hours. Cause not identified.

30 April 2011: RTG case voltage shifts occurred ➔ Low Rail shifted to 0V and High Rail to 30V ➔ This condition remained for 6 weeks.

11 Junes 2011: High Rail shorted to the chassis ➔ High Rail shifted to 0V and Low Rail to 30V ➔ CAPS was suspected to be involved and 4 days later: CAPS was intentionally turned off. Steady Low Rails 7V, High Rail 23V

Early 2012: NASA Engineering and Safety Center (NESC) conducted an analysis and concluded tin whiskers were the likely cause of the shorts.

18 March 2012: CAPS on, after 2 days bus level changed. RTG overall power decreased by 2W and recovered after a few hours. NESC conducted a 2nd analysis with result that differed from the 1st analysis. Ground testing reproduced internal short scenarios and recommended to turn CAPS off (June 2012). steady Low Rails 6V, High Rail 24V

Power Mission Requirement Discussion

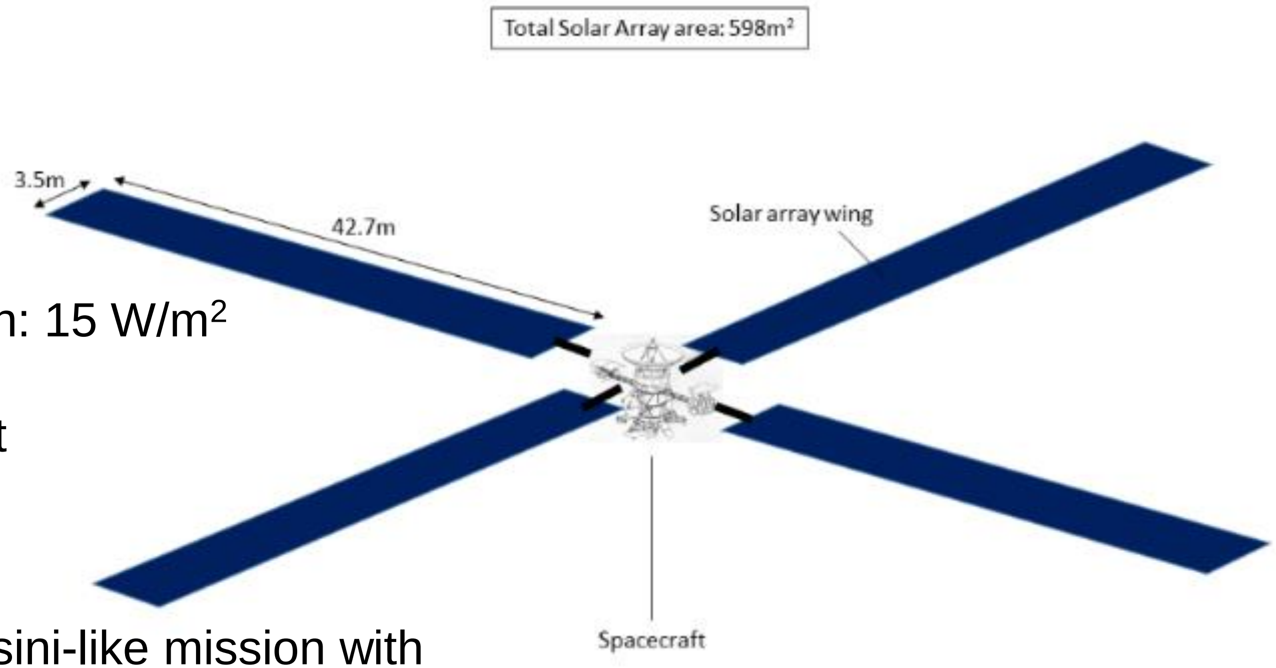
The Cassini power performance over the 20 year lifetime of the mission mimics the historical performance of RTGs for many deep space missions.

RTG: Excellent record in extreme solar range and high radiation environments.

NASA chose to use RTG power for the Cassini mission based on a number of technical factors, including lower mass and improved attitude control compared to necessarily large solar arrays.

Solar cell efficiency has shown steady improvement over the years since Cassini was developed. For 60.35 m^2 solar powered Jupiter mission Juno, limiting radiation degradation and optimizing Low Intensity and Low Temperature (LILT) performance ➔ 416W at end of mission

Power Mission Requirement Discussion



Saturn: 10 a.u.

Solar intensity at Saturn: 15 W/m^2

Solar intensity (AM0) at earth:1366.1 W/m^2

300 m^2 array for a Cassini-like mission with the current solar cell technology

Even with these advances in solar cell/array technology, a Cassini-type mission with a similar science instrument payload would most likely still require a RTG power system solution.

Cassini Program Environmental Impact Statement Supporting Study. 1994, JPL.